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ABSTRACT

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The long-accepted hypothesis that the nucleus of the Crab Nebula is a remnant of the 1054 supernova is subjected to a critical re-examination in the light of recent evidence. More particularly, Kraft's data and his subsequent inference that the central star of the Crab nebula could be a common star occupying its centermost position by virtue of chance are challenged on statistical grounds. Then, rejecting both the single-supernova and chance-centralization assumptions, the author advances the fresh hypothesis that the observed star is one member of a double system, its partner having exploded into a supernova whose remnant is not optically observable. Arguments pro and con the hypothesis are presented, but it is strongly favored by the strikingly large proper motion of the star, among other features brought under discussion.

Author

During the last two decades (or, more precisely, since the work of Baade (ref. 1) and Minkowski (ref. 2)), it has been supposed that one of the two closely associated 15th magnitude stars found in the central portion of the Crab nebula might be a supernova remnant. This supposition, of course, has never been accorded any truly meaningful substantiation, but was made primarily on the evidence of the central location of this star. According to reference 1, the color index of the star is equal to 0.14, corresponding to the spectral class F1. The spectral energy distribution subsequently found by Minkowski indicated a fairly high spectrophotometric temperature, which provided an extra argument in favor of the hypothesis that this star was a postsupernova. Recently, however, Kraft found H and K lines in its spectrum, whence he decided that this was a common F-type star, accidentally projected onto the Crab nebula and not genetically related to it (ref. 3). According to reference 3, there is no star brighter than 18^m in the center of the Crab nebula.

Nevertheless, a more careful analysis of the problem compels us to doubt the validity of this conclusion. It is scarcely possible, for example, to subscribe to the chance central location of a star with respect to the Crab nebula. The physical center of the Crab nebula, where it is generally considered that one finds the source of continuing activity and powerful emanations of energy, has been rather well fixed. Based on an analysis of the well known observations of Baade (see ref. 4), along with unpublished photographs by Münich, it may be asserted that the source of activity of the Crab nebula is situated in a region including the central star and having a radius less than 3". According to the data of stellar statistics, on the other hand, the mean density of 15th magnitude stars in the region of the galactic equator is ~ 0.5 stars per square minute. It follows immediately from this that the probability of a 15th magnitude star falling by chance within a small region 3" in radius is less than 10^{-2}. In addition to this, the star in which we are interested has a spectral class F. It is quite certain that only stars of this spectral class, having a photovisual magnitude in the visible range of 15.5 (ref. 1), can be found at distances equal to that of the Crab nebula (1.4 kiloparsecs). It is important here to allow for interstellar light absorption, amounting to $\sim 1^m$.

In a priori probability that a type F star will be located by chance in the vicinity of the physical center of the Crab nebula is slmost 10^{-3}. We have no choice but to make the basic assumption that the F star and Crab nebula are genetically related.

On the other hand, the trivial nature of this star rejects the hypothesis that it is a postsupernova. It seems reasonable in this situation to hypothesize that the observed star is one component of a double system, the second component having exploded into a supernova and at present not optically observable. There exists one conclusive fact clearly supporting our hypothesis. Even Baade (ref. 1) was intrigued by the relatively large proper motion of the star which had previously been regarded as a postsupernova. In fact, according to Duncan (ref. 5), the proper motion of this star is $\mu_\alpha = -0''.019, \mu_\delta = 0''.000$, as opposed to another near star in the central region of the Crab nebula, for which $\mu_\alpha = 0''.000, \mu_\delta = 0''.002$. The old Pulkovo measurements of Deych and Lavdovskiy are in good agreement with Duncan's results, giving for the star in question $\mu_\alpha = -0''.018$, $\mu_\delta = 0''.002$ (ref. 6). Deych and Chudovicheva recently repeated the measurements, using a new epoch, and confirmed this result. The probable error of the above measurements did not exceed $\pm 0''.003$. We note that, according to reference 1, on the basis of the observations of van Maanen and Baade $\mu_\alpha = -0''.010$, i.e., just about half the previously cited values. This result, however, disagrees with the three independent measurements described above and carries very little weight. It is interesting that the proper motion of the entire system of filaments comprising the Crab nebular, according to reference 5, is close in magnitude and has the same sign: $\mu_\alpha = 0''.022 \pm 0''.007$. This result is not supported, incidentally, by the recent measurements of Deych and Chudovicheva.

If the distance to an F-type star is equal to the distance of the Crab nebula, then the tangential component of its peculiar velocity is about 130 km/sec, which is five or six times greater than the velocity dispersion for type F stars. Such a high peculiar velocity can also be explained in much the same way that Blaauw recently explained the nature of the rapidly moving O-type stars (ref. 7). Namely, after the explosion of one component of a double system, with the concomitant ejection of most of its material mass at enormous velocities, the second component will move with an almost constant orbital velocity. If, for example, we assume that the initial masses of both components were identical and each equal to $1.3\ M_\odot$, it follows from the stipulation that the angular velocity was equal to the observed spatial velocity of the unexploded component ($\sim$150 km/sec, allowing for the as yet unknown radial velocity), that the distance between components prior to explosion was $\sim 4 \cdot 10^{11}$ cm, or $\sim 6\ R_\odot$ (on the premise that the orbit is circular). The remnant of the star after the explosion will almost invariably move together with the unexploded star, its orbit suffering considerable alternations (becoming, for instance, acutely elliptical).

We are distinctly aware of the difficulties that our hypothesis will encounter. The main ones are as follows: a) The mass of the gases expelled by the explosion should be close to that of the sun, whereas the existing estimates for the mass of the gaseous shell of the Crab nebula yield a value one order of magnitude smaller (see, e.g., ref. 8); b) the law of conservation of momentum demands that the velocity of the center of gravity of the gaseous shell expelled by explosion oppose the velocity of the star, which is possibly in conflict with existing obervations (see above).

The first difficulty can be removed by assuming that the greater mass of filaments comprising the Crab nebula consists of neutral gas. We note that this assumption is favored by the presence of the line λ 6300 (OI) in the spectrum of the Crab nebula. The second difficulty may be circumvented by any of several means, which we will not discuss here, especially since the proper motion of the Crab nebula still remains an unresolved problem.

The assumption that the 1054 supernova was an intimate double system paves the way to new interpretations of the phenomena occurring in the Crab nebula. If, in particular, we regard accretion of gases by the contracting star as the cause of the continuing activity of the nucleus and the Crab nebula (ref. 9), then the observed $\sim$60-day periodicity of the metamorphoses in the central portion of the Crab nebula (ref. 4) can be attributed to the motion of the explosion remnant, or collapsing star, in a very elongated ellipse about the observed F star. The period of revolution is $\sim$60 days, the stars coming into very close proximity at the periastron. This close approach can result in expulsion from the F star of powerful streams of gases, which impinge on the collapsing star. This expulsion process takes several hours, followed by a relatively quiet period lasting two months.

It is not overlooked that the effect of duality, or multiplicity in general, is a fundamental property of all exploding stellar objects. This is true in particular for supergiants. Conceivably, the 13-year period of the oscillations in luminosity of 3C-273, as well as the notable 3- to 5-year period of the luminosity oscillations of 3C-48 are caused by periodic variations in accretion or motion of condensing objects in eccentric orbits. It is also relevant at this point to recall that the common nova are closely associated double systems (ref. 11).

In order for the hypothesis of duality of the nucleus of the Crab nebula to be verified, extended and careful spectrophotometric, as well as electrophotometric, observations are first of all needed with respect to the star at the center of the nebula. Such observations, for example, could provide evidence of spectral duality, the presence of flares repeated every $\sim$60 days, and certain other possible singularities.

P. K. Shternberg State Astronomical Institute

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REFERENCES

1. Baade, W. Astrophys. J., Vol. 96, p. 188, 1942.

2. Minkowski, R. Astrophys. J., Vol. 96, p. 199, 1942.

3. Hoyle, F., Fowler, F., Burbige, G. and E. Burige. Preprint, Caltech, 1963. (See Astrophys. J., Vol. 139, No. 3, p. 909, 1964).

4. Oort, J.H. and T. Walraven. Bull. Astron. Neederlands, Vol. 12, p. 285, 1956.

5. Duncan, J.C. Contributions from the Mount Wilson Observatory, No. 609, 1939.

6. Deych, A.N. and V.V. Lavdovskiy. Poulcovo Obs. Circ., No. 30, p. 28, 1940.

7. Blaauw, A. Bull. Astron. Inst. Neth., Vol. 15, p. 265, 1961.

8. Osterbrock, D.E. Publ. Astron. Soc. Pacific, Vol. 70, p. 180, 1958.

9. Zel'dovich, Ya. B. Doklady Akad. Nauk SSSR, Vol. 155, p. 67, 1964.

10. Sandage, A. Astrophys. J., Vol. 139, p. 416, 1964.

11. Kraft, R. Astrophys. J., Vol. 139, p. 457, 1964.

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